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# Sedimentology and Preliminary Assessment of the Industrial Applications of Shale Facies in the Ogwashi-Asaba Formation, Niger Delta Basin, Nigeria

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## Abstract
Sedimentological and major element oxide geochemical evaluation of shale facies in the Ogwashi-Asaba Formation outcrops in the Obomkpa area of Niger Delta Basin, was evaluated to preliminarily assess the industrial potentials of shales in this study. To assess the potentials of the shale as raw material for industrial purposes, representative samples obtained from outcrops were subjected to geotechnical and geochemical analyses using conventional wet sieve analysis method, Atterberg Limits and firing tests, and x-ray florescence (XRF). Field and laboratory sedimentological evaluation reveal a dark to black coloured, fissile shale lithology with sand percentages of 1 – 4 % and bed thickness variation of 1.8 – 4 m. Major element oxide wt. % show that $SiO_2$ ranged from 46.78 – 52.45%, (av. = 48.82%) and $Al_2O_3$ ranged from 25.33 – 29.82%, (av. = 27.05%) and make up 75.87% of the bulk chemical composition. Although little or no variability exists in the $SiO_2$ and $Al_2O_3$ contents between samples from various locations, major oxide variability exists between the shale and those of notable industrial clays. IL/MA ratios suggests disordered kaolinite/illite as the constituent clay mineral present in the shale, while a characterization based on the Cassagrande soils classification scheme revealed inorganic earth material of high compressibility and high plasticity. Fired shrinkage at 950°C and 1000°C and above ranged from 9 – 11% and 5 – 9% respectively. Fired colour change at 950°C and 1000°C and above remained reddish brown. Comparison of analysed properties of the shale with specifications of notable clays, reveal that the shale have potential industrial applications in the manufacture of acid-proof products, sanitary wares and glazing tiles, rubber production, cosmetic, paint and coating material for paper production, if appropriate beneficiation is done to improve their economic and industrial value.

***Keywords: Ogwashi-Asaba shale facies, industrial minerals, shale geochemistry, IL/MA ratios***

## 1. Introduction

Globally, shale forms a major sedimentologic and stratigraphic component of the geologic record. Their physical characteristics and chemical and mineralogical composition determines their industrial applications. “Shale” is clay that has been hardened by natural geologic processes, although when ground and moistened it will in many instances become plastic [Hamilton and Babet, 1975], as it is chiefly composed of clay minerals. Shale may appear different in physical attributes from the common clay due to the presence of sedimentary structures that results from aging and preserved organics that impacts a dark coloration in most instances. Commonly when shale is considered, it is not uncommon to view shale basically from the petroleum source rock perspective, just as the engineering geologist may constantly view shale as notorious in engineering project and construction sites

In Nigeria, outcrops of formational units across several basin areas reveal thick sequences of shale facies interbedded with other lithologies. These are common sights in road cuts, river cliffs and quarries sites. These exposures range in age from Mesozoic to Cenozoic. Some exposures of Mesozoic age include exposures of the Patti Formation [Jones, 1958; Akande et al. 2005, Ojo and Akande, 2008; Nwajide, 2013; Osokpor and Okiti, 2013; Osokpor et al., 2013] in the Middle Niger Basin, along the Lokoja-Abuja highway, especially around Ahoko town and at various locations; exposures of the Enugu Shale Formation in the Anambra Basin, exposed around Enugu and along the Enugu-Port Harcourt express road; the Nkporo Shale, also exposed along same route especially at Leru, and outcrops of the Mamu Formation exposed at various locations in the Anambra Basin. Good exposures of the Mamu Formation can be assessed in and around the area bordering the Onyema coal mines in Enugu, the Benin Flank area (around Auchi, Imiegba and Okpekpe), in coal quarries in the central area of the Anambra Basin in Kogi State (Okaba). Although these locations mentioned for the formations may be notable for outcrops of the formations, excellent exposures of the units abound in several other locations. Shale of the Odukpani Formation occur in the surface and subsurface in the Calabar Flank (Odukpani Formation). Cenozoic shale exposures can be found in the northern parts of the Niger Delta such as is seen in the Lignite belt of the Ogwashi-Asaba Formation [Osokpor and Osokpor, 2020], which is the focus of this study, also in the Imo Shale Formation [Okunlola and Egbulem, 2015], and in the Benin Basin. This listing above is by no means exhaustive.

Although exposures of shale is abundant in many basins in Nigeria, works on the industrial suitability and applications of clays has consistently focused and revolved round existing clay deposits. Very little economic evaluations of the industrial potentials of shale exposed in various basins in Nigeria compared to several works done on local clay deposits [Elueze and Bolarinwa, 1995, 2001; Nton and Elueze, 2005; Emofurieta et al, 1994; Elueze et al. 1999; Imeokparia and Onyeobi, 2007; Akhirevbulu et al. 2010; Osokpor and Osokpor, 2020] etc exists.

The industrial application of shale locally falls short of economic expectation considering the urgent need to diversify the Nigerian Economy. The shale of the Patti Formation was been quarried and utilized for tile production in recent past prior to the year 2010, but the operation was short-lived. Although studies on the composition, mineralogy and economic/industrial appraisal of Nigerian shale abounds [Obrike et al., 2007; Okunlola and Egbulem, 2015; Oyedele et al., 2018; Ayajuru et al., 2019], actual statistics and use on the volume of locally exploited and exploitable shale resources is generally not readily available.

In Egypt, shale has been widely used in the production of brick [IDRC, 1992], while in India and in Kansas, USA, etc., several shale deposits has been exploited for various economic purposes. This indicates that great opportunities abounds in shale exploitation as it could be an important foreign exchange earner.

This work seeks to carry out a sedimentological evaluation and preliminary industrial suitability assessment of shale facies units present in the Ogwashi-Asaba Formation (Fig. 1), based on geotechnical and comparative geochemical attributes of the shale with industrial specifications.

## 2. Materials and Mthods

### *2.1 Geology and Stratigraphy*

The regional geology of the Niger Delta Basin is discussed in many current articles and thus need be dealt with only briefly here. The Niger Delta Basin is renowned for its huge petroleum resources, although vast potential exist in the solid mineral resources that is mainly assessed in surface exposures delta wide. Six geological formations are present in the Niger Delta Basin, although three of these are most commonly mentioned. From the proximal to distal delta are the Imo Shale, Ameki and Ogwasi-Asaba Formation (Doust and Omatsola 1990), which exists in the northern aspects and the Akata, Agbada and Benin Formations [Reyment, 1965; Frankl and Condry 1967; Short and Stauble 1967; Adegoke 1969; Whiteman 1982; Nwajide 2013], which constitute the geological units in the central to southern areas. The formations present in the central and southern parts of the delta are lateral equivalents of those present in the northern parts, thus make the Niger Delta formations to be characteristically age-diachronous (Fig. 2).

The Ogwashi-Asaba Formation which was originally named Lignite Series [Parkinson 1907], consists of white, blue and pink clays interbeds cross-bedded sands, carbonaceous mudstones, and lignites interbedded in thick black shale [Okezie and Onuogu 1985; Nwajide 2013]. Reyment [1965], Short and Stauble [1967] and Dessauvagie [1974] advanced an age range of Oligocene-Miocene (Fig. 2). Okezie and Onuogu [1985] based on pollen data, classed the lignites as products of tropical and semi-tropical climatic condition, inferred to have been deposited in upper flood plain environment [Short and Stauble 1967].

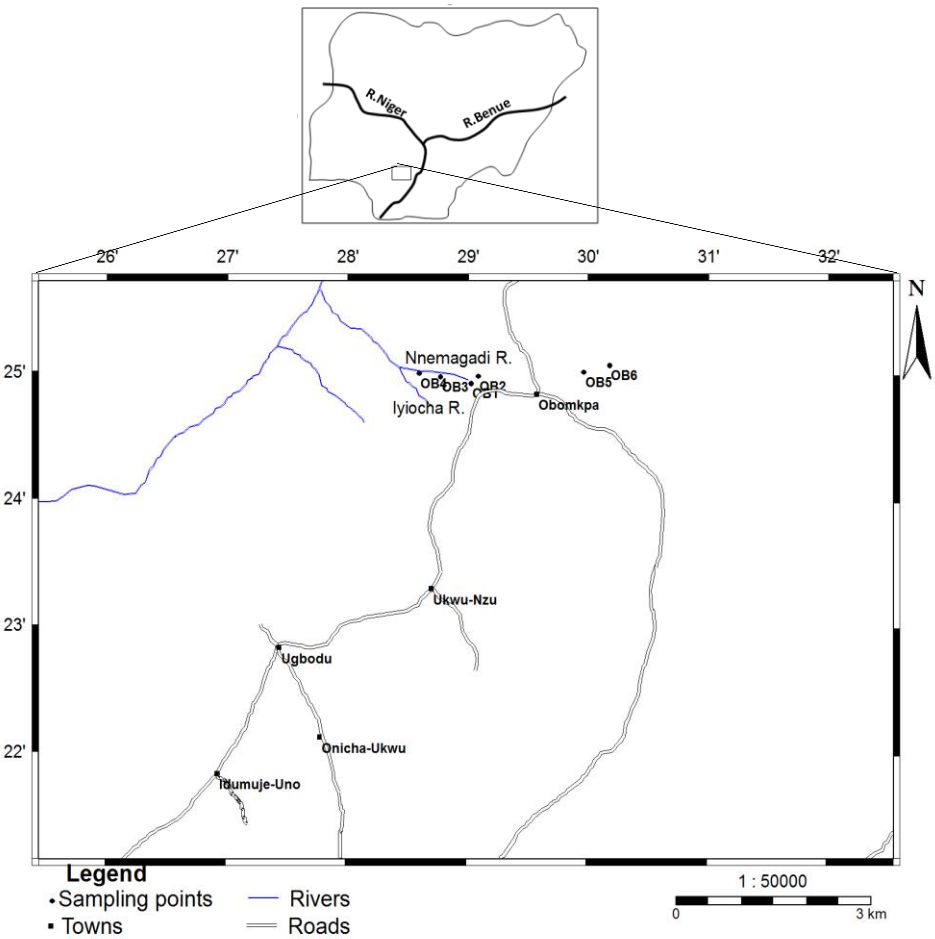


Fig 1. Location map of study area showing sample collection points in and around Obomkpa.

The outcrops from which shale samples were obtained for this study, consists of dark shales bounding lignite seams exposed in the thick tropical rain forest around Obomkpa town. The Obomkpa area is renowned for very good exposures of the lignite and shale facies of the Ogwashi-Asaba Formation.

| SUBSURFACE | | SURFACE OUTCROPS | | | BASIN |
|---|---|---|---|---|---|
| Niger Delta Basin Stratigraphy | Oldest known Age | Youngest known Age | Southern Benue Trough | Oldest known Age | |
| Recent Benin Formation | Oligocene | Recent | Benin Formation | Miocene | Niger Delta |
| Recent Agbada Formation | Eocene | Miocene | Ogwashi-Asaba Formation | Oligocene | |
| | | Eocene | Ameki Formation | Eocene | |
| | | | Imo Shale Formation | Paleocene | |
| Recent Akata Formation | Eocene | Eocene | Nsukka Formation | | |
| | | | Ajali Formation | Maastrichtian | Anambra |
| | | Campanian | Mamu Formation | Campanian | |
| | | Campanian/ Maastrichtian | Nkporo Shale | Santonian | |
| Unknown | Cretaceous | Coniacian/ Santonian | Awgu Shale | Turonian | Abakaliki |
| | | Turonian | Eze-Aku Shale | Turonian | |
| | | Albian | Asu River Group | Albian | |

Fig. 2. Geological formations of the Niger Delta Area, Nigeria [Modified from Short and Stauble 1967]

### *2.2 Investigative methods*

Six non-composited shale samples from outcrops exposed in the forested woodland area of Obomkpa community, in Delta State, were obtained for this study.

### *Sedimentological Analysis*

Shale samples obtained in the field were initially examined in hand specimens and described for lithologic attributes such as the presence of sand grains, organic debris, presence of sedimentary structures (fissility, lamination, etc.), and state of consolidation.

The samples were then initially air-dried at room temperature, and sieved to remove large particles and organic debris such as vegetal materials at the laboratory stage of investigation. 25g of each sample was then wet-sieved by hydrometer testing method to obtain the size distribution of the component grains.

### *Major Element Analysis: X-Ray Fluorescence Spectrometry (XRF)*

With the aid of a Mettler Toledo PL602-S electrical weighing balance, 25g of air-dried sample was each weighed out and prepared for major elements analysis. Each weighed out sample was then dried at 60°C and pulverized using a mild-steel pulveriser (PUL85) to 85% passing 200 mesh (75 microns).

Determination of Loss on Ignition (LOI) was done by roasting a predetermined quantity of each sample due for analysis before been analysed for geochemical attributes using XRF method. Heated sample was subsequently fused in a platinum-gold receptacle with a commercial Lithium Tetraborate ($LiBO_4$) flux. The liquefied material was cast in a platinum form and the fused discs analysed for major elements by an X-Ray Fluorescence Spectrometer. For QA and QC of analytical results, Diorite Gneiss (SY-4) was used as a standard reference material.

### *2.3 Geotechnical Testing*

Hydrometer testing method done on six shale samples to define grain size distribution as an initial theoretical stage to describe the sediments, after which the determination of the Atterberge Limits (plastic limit, liquid limit, and plastic index) in accordance with BS 1377 was done: part 2 and water absorption capacity test undertaken in in line with ASTM description C 128.

## 3. Results and Discussion

### *3.1 Lithofacies Description*

A single lithofacies is described for the shale. The shale is characteristically soft dark to black coloured, clean fissile shale with characteristic disseminated black organic materials that can be seen when dried, disaggregated and viewed under transmitted light microscope. The sand content ranged from 1 – 4 %. The shale facies enclose thick seam of coal in the different locations where it was mapped for sampling, with thickness variation which ranged from 1.8 – 4m in places depending on the thickness of the overburden and the geomorphology of the area where the shale outcrops (Fig. 3).

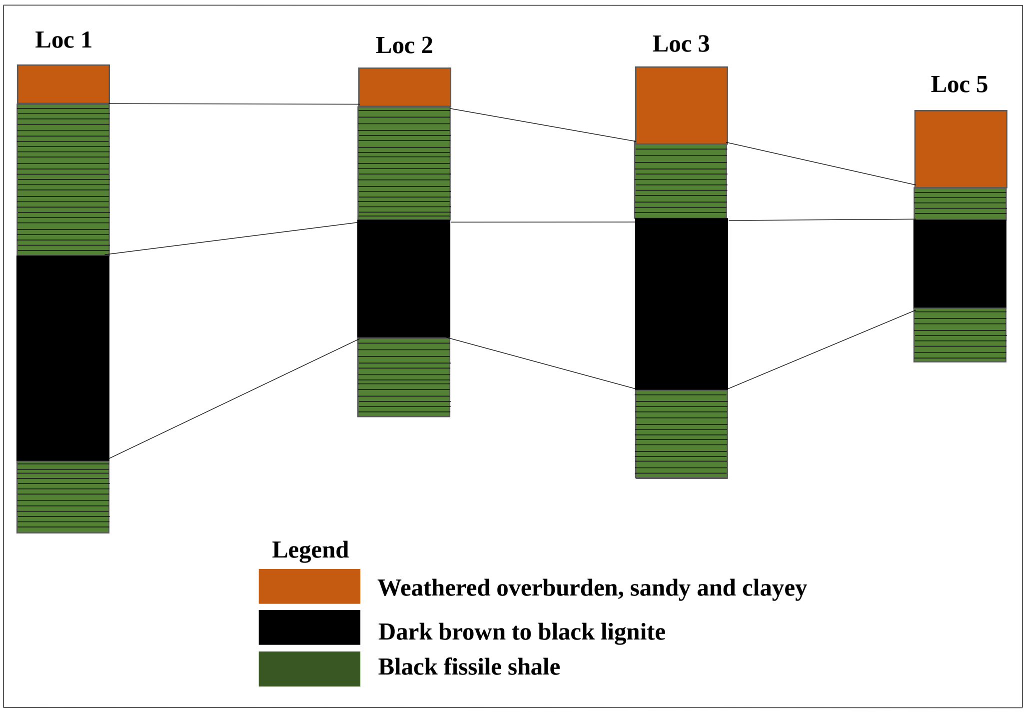


Fig. 3. Lithological sections of the shale showing thickness variation of the shale at different locations

***Major Element Oxides***

Oxides of major elements in the shale accounts for between 70 – 88 % of the shales, while 12 – 30% is attributed to water, trace elements, and organic constituent (Table 1). Values of oxides in the sediments were compared with the average oxide values of notable clays (Table 2). The shales exhibit compositional variability in the average silica content, with an overall average of 48.82 wt. % lower than values of the Average clay-shale (AVCS) [Petijohn 1957], Plastic Fire Clay (PFC) [Huber 1985], Florida active Kaolinite [Huber 1985], and Average Esan and Asaboro clays [Osokpor and Osokpor 2020], but higher that values of the Florida non-active kaolinite and China clay [Huber, 1985] and Afam clay [Jubril and Amajor 1991] (Table 2). The average alumina content of the shales (av. = 47.05), is high compared to values present in the notable clays above, China clay (37.65), Florida non-active clays (38.85), Afam clay (26.20), Plastic fire clay, (24.00), Average clay-shale (15.40), and Florida active kaolinite (9.42). $Fe_2O_3$ concentrations range from 2.76 – 4.2 (av. = 3.27). The refractories, CaO (range = 0.06 – 0.26, av. = 0.14), MgO (range = 0.15 – 0.25, av. = 0.19) and MnO (range = < 0.01 – 0.04, av. = 0.02), and the Alkalis, $K_2O$ (0.28 - 0.55, av. = 0.42) and $Na_2O$ (< 0.01 – 0.01) occur in relatively insignificant proportions. These values indicate high degree of chemical weathering under tropical humid conditions. Significant chemical variations does not exist between the six samples from the different location across the area sampled in terms of the silica and alumina contents, and the close correspondence indicate that the sample are from same geologic unit.

Table 1: Composition and Concentrations of Major Elements in the Samples

| | | SAMPLES | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Element | Detection Limit (Wt. %) | OB1 | OB2 | OB3 | OB4 | OB5 | OB6 | Average |
| $SiO_2$ | 0.01 | 49.04 | 46.78 | 51.20 | 47.56 | 45.90 | 52.45 | 48.82 |
| $Al_2O_3$ | 0.01 | 29.82 | 25.76 | 25.33 | 26.32 | 29.25 | 25.82 | 27.05 |
| $Fe_2O_3$ | 0.01 | 2.76 | 4.09 | 2.45 | 3.25 | 4.2 | 2.85 | 3.27 |
| CaO | 0.01 | 0.26 | 0.09 | 0.08 | 0.06 | 0.15 | 0.18 | 0.14 |
| MgO | 0.01 | 0.23 | 0.17 | 0.15 | 0.19 | 0.25 | 0.17 | 0.19 |
| $Na_2O$ | 0.01 | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 | 0.01 |
| $K_2O$ | 0.01 | 0.28 | 0.36 | 0.55 | 0.32 | 0.45 | 0.53 | 0.42 |
| MnO | 0.01 | 0.01 | <0.01 | 0.02 | 0.04 | 0.02 | 0.03 | 0.02 |
| $TiO_2$ | 0.01 | 1.48 | 1.87 | 2.99 | 3.20 | 1.95 | 1.63 | 2.19 |
| $P_2O_5$ | 0.01 | 0.06 | 0.09 | 0.07 | 0.05 | 0.07 | 0.10 | 0.07 |
| $Cr_2O_3$ | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 |
| LOI | - | 15.47 | 20.11 | 16.79 | 18.22 | 17.54 | 16.16 | 17.38 |
| SUM | - | 99.43 | 99.35 | 99.64 | 99.24 | 99.82 | 99.95 | 99.57 |
| $Al_2O_3/Fe_2O_3$ | | 10.80 | 6.30 | 10.34 | 8.10 | 6.96 | 9.06 | 8.59 |

Table 2: Average chemical composition of the Ogwashi-Asaba clay compared with average chemical composition of other clay types

| Oxide **%** | Average Ogwashi-Asaba Clay | Average clay-shale [Pettijohn 1957] AVCS | Afam clay [Jubril & Amajor 1991] AFCS | Florida non-active kaolinite [Huber 1985] | Florida active Kaolinite [Huber 1985] | Plastic fire clay St Louis [Huber 1985] PFC | China clay GTY [Huber 1985] SCC |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 48.82 | 58.10 | 42.20 | 45.57 | 52.92 | 57.67 | 46.88 |
| $Al_2O_3$ | 27.05 | 15.40 | 26.20 | 38.45 | 9.42 | 24.00 | 37.65 |
| $Fe_2O_3$ | 3.27 | 4.24 | 5.10 | 0.75 | 3.65 | 3.23 | 0.88 |
| CaO | 0.14 | 3.11 | 1.60 | - | 1.91 | 0.70 | 0.03 |
| MgO | 0.19 | 2.44 | 0.70 | 0.05 | 0.08 | 0.30 | 0.13 |
| $Na_2O$ | 0.01 | 1.30 | 2.90 | - | 0.03 | 0.20 | 0.21 |
| $K_2O$ | 0.42 | 3.24 | 8.30 | 0.06 | 0.98 | 0.50 | 1.60 |
| MnO | 0.02 | - | 0.03 | - | - | - | - |
| $TiO_2$ | 2.19 | - | - | 0.01 | 1.18 | - | 0.09 |
| $P_2O_5$ | 0.07 | - | - | - | 0.02 | - | - |
| $H_2O^+$ | 17.38 | - | - | - | 10.19 | 10.50 | 12.45 |
| $SiO_2/Al_2O_3$ | 1.80 | 3.77 | 1.61 | 1.19 | 5.62 | 2.40 | 1.25 |

### *3.2 Geotechnical Properties*

**Atterberge Limit**

Grain size analysis and geotechnical results (Atterberg limits, water absorption properties and shrinkage), tested for are presented in Tables 3 and 4.

Plastic and liquid Limits are the Atterberg Limits determined. These were used to compute the plasticity indices. Plasticity indices for the sediments range from 42.50 – 49.36 % (Table 3). The larger the plasticity index, the more plastic and compressible, and the greater the bulk change properties of the clays.

Table 3: A Summary of particle size distribution, liquid limit, plastic limit and plasticity index results of fines in the studied samples

| Shale Sample | Natural Moisture Content % | Particle Size Distribution | | | | Atterberge Limits | | | USCS |
|---|---|---|---|---|---|---|---|---|---|
| | | Clay % | Silt % | Sand % | Fines % | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) | |
| 1 | 12.7 | 90 | 7 | 3 | 97 | 65.13 | 18.12 | 47.01 | CH |
| 2 | 12.4 | 91 | 5 | 4 | 96 | 62.36 | 19.56 | 42.80 | CH |
| 3 | 11.7 | 93 | 6 | 1 | 99 | 70.00 | 20.64 | 49.36 | CH |
| 4 | 13.3 | 89 | 8 | 3 | 97 | 64.84 | 22.34 | 42.50 | CH |
| 5 | 13.5 | 95 | 4 | 1 | 99 | 69.67 | 24.15 | 45.52 | CH |
| 6 | 12.9 | 92 | 5 | 3 | 97 | 62.98 | 20.32 | 42.66 | CH |

LL = Liquid Limit
PL = Plastic Limit
IP = Plasticity Index
Gs = Particle Specific gravity
IL = Ignition Loss (Loss on Ignition)
MA = Moisture Adsorption
USC = Unified Soil Classification
CH = Inorganic clay of high compressibility and high plasticity

**Inferred Mineralogical Constitution**

Mineralogical analysis to characterize the shale in order to decipher the constituent clay mineral species was not done, although an attempt to characterize the mineralogical composition was indirectly achieved [Keeling 1961; Osokpor and Osokpor 2020]. This involved the use of the ratio of loss on ignition (IL) and moisture absorptive (MA) capacity of the shale (Tables 5 and 6). In the computation in Table 6, the IL/MA ratios for each analysed sample fall within a range of 1 – 2. This indicate that the shale is composed of disordered kaolinite and illite (Table 6).

Table 4: Fired Shrinkage and Colour Change of the Clays

| Sample | | At 950°C | | | At 1000°C and above | | | colour | |
|---|---|---|---|---|---|---|---|---|---|
| | Dry Diameter (cm) | Fired Diameter (cm) | Linear Shrinkage (cm) | % Shrinkage | Fired Diameter (cm) | Linear Shrinkage (cm) | % Shrinkage | Colour before firing | At 1000 - 1100°C |
| 1 | 3.50 | 3.12 | 0.38 | 11 | 3.12 | 0.18 | 6 | Dark Grey | Reddish brown |
| 2 | 3.50 | 3.15 | 0.35 | 10 | 3.15 | 0.21 | 7 | Dark Grey | Reddish brown |
| 3 | 3.50 | 3.17 | 0.33 | 9 | 3.17 | 0.28 | 9 | Dark Grey | Reddish brown |
| 4 | 3.50 | 3.11 | 0.39 | 11 | 3.11 | 0.16 | 5 | Dark Grey | Reddish brown |
| 5 | 3.50 | 3.18 | 0.32 | 9 | 3.18 | 0.29 | 9 | Dark Grey | Reddish brown |
| 6 | 3.50 | 3.12 | 0.38 | 11 | 3.12 | 0.17 | 5 | Dark Grey | Reddish brown |

Table 5: Water Absorption (Porosity) of Fired Clay at > 1000°C

| Sample | Original wt. (gms.) | Soaked wt. (gms.) | Increase in wt. (gms.) | % Water Absorption | IL/MA |
|---|---|---|---|---|---|
| 1 | 12.00 | 12.82 | 0.82 | 0.06 | 1.22 |
| 2 | 12.00 | 12.75 | 0.75 | 0.06 | 1.62 |
| 3 | 12.00 | 13.12 | 1.12 | 0.09 | 1.44 |
| 4 | 12.00 | 12.81 | 0.81 | 0.01 | 1.37 |
| 5 | 12.00 | 13.51 | 1.51 | 0.11 | 1.30 |
| 6 | 12.00 | 12.78 | 0.78 | 0.06 | 1.29 |

Table 6: IL/MA ratio classification of clay minerals based on the [keeling 1961]

| mineral | IL/MA ratio |
|---|---|
| Well crystallized Kaolinite | > 7 |
| Intermediate Kaolinite | 3 - 7 |
| b-axis disordered Kaolinite | 2 - 3 |
| Disordered Kaolinite/Illite | 1 – 2 |
| Illite | 0.7 – 1 |
| Smectite | 0.3 – 0.7 |

IL: Loss on Ignition, MA: Moisture absorption

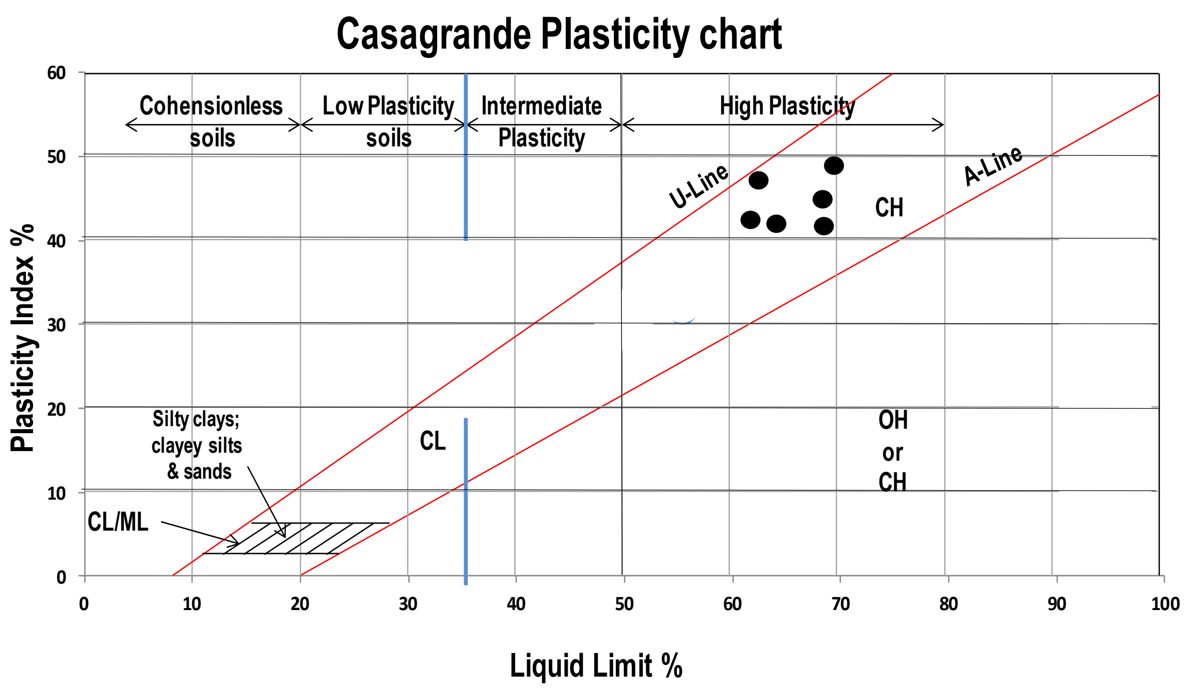

Fig. 4. Classification of the samples from the study area on a Casagrande [1948] soil classification plot.

Values from all the samples plot above the A-line in the Casagrande [1948] soil classification plot (Fig. 4). Therefore the sediments are classified as inorganic clays according to the Unified Soil Classification System [USCS 1967], as inorganic clay of high compressibility and high plasticity (CH) (Table 3) with LL > 60 (Fig. 4).

The liquid limits for the samples range from 62.36 – 70, while the plasticity index range from 42.50 – 49.36 (Table 3). The high values recorded for the PI is not unrelated to the high percentage of fines in the sediments, as soils with high amounts of clay are characterized by high plasticity indices, very compressible and cohesive. Thus the shale could be inferred to possess high compressibility and very cohesive (Table 3). The plasticity limits range from 18.12 – 24.15%. Plasticity limits of 10 – 60% of clay materials has been shown to be suitable for ceramic production [Grimshaw 1971], indication the suitability of the shale under study for ceramic production. High plasticity materials as obtained in this study, are commonly blended with cohension-less granular materials like fine sand to reduce the plasticity, the expected excessive drying and firing shrinkages and the resultant internal cracking [Akpokodje et. al. 1991].

The sieve analysis values reveal the grain size distribution in each samples. This distribution presents an initial inherent sedimentological characteristics of the shale (Table 1). A close correlation exist between the grain size distribution data and the Atterberg limits derived for the samples, as samples with higher percentage of fines exhibit higher plasticity index (Table 3).

The shale of the Ogwashi-Asaba Formation is classed as inorganic clay of high plasticity as the Atterberg limits values plot above the “A” line Casagrande chart (Fig. 4). Inorganic clays are separated from silty and organic soils by the “A” line.

The shrinkage at 950°C and 1000 - 1100°C ranged from 9 – 9 % and 5 – 9% respectively (Table 4). Water absorption capacity ranged from 6 – 11%. This can infer the presence of internal cracking in some of the samples. Colour characteristics of the shale after firing at 1000 - 1100°C changed from dark grey to reddish brown.

***Potentials Industrial Applications of the Clays***

The suitability and application of clays for industrial applications is dependent on the physical characteristics, mineralogical and chemical composition.

A comparison of the constituent major oxide properties of the sediments in this study with the industrial requirements of some important clays (Table 7) indicate that shale from the Ogwashi-Asaba Formation could find good use in the production of refractory bricks [Parker 1967] if the $Fe_2O_3$ content is reduces through chemical beneficiation and the $Na_2O$ content improved upon. Also the shale would be suitable for the production of ceramics [Singer and Sonja 1971] if the silica, $Na_2O$ and $K_2O$ content is improve upon and a corresponding reduction of the alumina, $Fe_2O_3$, and $TiO_2$ content, also considering the range of plasticity limits as stated above.

The application of the shale in rubber production will require reduction in silica and $K_2O$ content, and improvement of the alumina and $Na_2O$ content by blending with clays that have appropriate quantities of alumina and $Na_2O$ in order to attain the industrial specification of clay meant for rubber manufacturing [Keller 1964], although the considerably high $Fe_2O_3$ content which causes undesirable colouration effect on the finished products may render the shale unsuitably for this application.

The Ogwashi-Asaba Formation shale are considered based on the alumina-iron ratio value of 8.59 less suitable for good quality cement production as a range of alumina-iron ratio of 1.71 – 2.45 is required for clays used in the production of good quality cement [Abatan et al. 1993].

An assessment of the chemical composition of the shale with the industrial specification as coating and filler in paper production [ANON 1972], (Table 7), show that if appropriate beneficiation is done to improve the geochemical constitution of the shale, it can find use in the paper industry.

Table 7: Comparison of major oxides tested in studied samples compared with chemical industrial specification

| Oxide % | Average Ogwashi-Asaba Shale | Reference | | | Paper [ANON 1972] | | |
|---|---|---|---|---|---|---|---|
| | | Refractory bricks [Parker 1967] | Rubber [Keller 1964] | Ceramics [Singer and Sonja 1971] | As coating | As Filler | Brick clay [Murray 1960] |
| $SiO_2$ | 48.82 | 51-70 | 44.90 | 67.50 | 47.80 | 48.70 | 38.67 |
| $Al_2O_3$ | 27.05 | 25-44 | 32.35 | 26.50 | 37.0 | 36.0 | 9.45 |
| $Fe_2O_3$ | 3.27 | 0.5-2.40 | 0.43 | 0.5-1.20 | 0.58 | 0.82 | 2.70 |
| CaO | 0.14 | 0.1-0.2 | - | 0.18-0.30 | 0.04 | 0.06 | 15.84 |
| MgO | 0.19 | 0.2-0.7 | - | 0.1-0.19 | 0.16 | 0.25 | 8.50 |
| $Na_2O$ | 0.01 | 0.8-3.50 | 0.14 | 0.20-1.50 | 0.10 | 0.10 | 2.76 |
| $K_2O$ | 0.42 | - | 0.28 | 1.10-3.10 | 1.10 | 2.12 | 2.76 |
| MnO | 0.02 | - | - | - | - | - | - |
| $TiO_2$ | 2.19 | 1.0-2.80 | 1.80 | 0.10-1.0 | 0.03 | 0.05 | - |
| $Al_2O_3$/ $SiO_2$ | 0.55 | - | 0.72 | 0.39 | 0.77 | 0.74 | 0.24 |
| $SiO_2$/ $Al_2O_3$ | 1.80 | - | 1.39 | 2.55 | 1.29 | 1.35 | 4.09 |

The high percentage of clay fraction (89 – 95 %) and low silt (4 – 8 %) and sand percent (1 – 4 %) in the shale samples, a sedimentological attributes required for the use of clays in the cosmetic and paint industry, makes the shale suitable for the manufacture of cosmetics and paint. Although the silt and sand fractions are generally low, these still acts as a constraint that reduces their suitability in their raw state, hence filtration to remove these coarser fraction that make them gritty is required to improve their prospective application in the manufacturing of cosmetics and paints.

Considering the compositional similarities between the shale and the plastic fire clay (PFC) of St. Louis [Huber 1985]; if adequate beneficiation is done the shale can be applied in the manufacture of sanitary wares, acid-proof products and glazing tiles.

**Conclusion**

The preliminary industrial potentials of shale sediments from outcrops of the Ogwashi-Asaba Formation in the northern Niger Delta area based on geochemical and geotechnical attributes revealed a broad applicability of the shale in a range of industrial concerns such as in the ceramics, rubber and plastic, cosmetics and paint industries, etc. The full potentials of the shale would be realized if adequate beneficiation is done depending on industrial requirement, to improve the quality of the material.

Although the mineralogical typing of the shale was inferred by the IL/MA ratio method of Keeling [1961], an actual mineralogical analysis using x-ray diffraction (XRD) method, would be required to ascertain the actual mineralogical constitution of the shale. Data from this study and previous studies as highlighted above, has revealed the huge potentials that abounds if shale rocks within Nigeria`s geological space is harnessed for industrial purposes.

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